



METHOD AND SYSTEM FOR RADIO COMMUNICATIONS USING  
MOBILE TERMINAL MOVING ROUTE PREDICTION

5 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to radio communication  
system and method for providing broadband packet  
10 communications with respect to subscribers moving by  
automobiles, etc.

DESCRIPTION OF THE RELATED ART

In conjunction with explosive spread of the Internet,  
15 it has become feasible to make accesses to images or  
applications such as execution files through the Internet  
not only from indoor environments such as home or office  
but also from outdoor environments such as street or inside  
a moving automobile. In particular, a service for  
20 downloading files containing music, video, advertisement  
information, etc., through the Internet is expected to be  
the major way for utilizing the Internet in the outdoor  
environments.

In the case of utilizing the Internet from the outdoor  
25 environment, a subscriber will access the Internet by  
utilizing a mobile communication system such as that of  
mobile phone or cellular phone. However, the current  
transmission bandwidth (about several tens Kbit/sec.) of  
the mobile communication system is hardly sufficient for  
30 comfortably receiving the service through the Internet.

There are also discussions of a next generation radio  
access system such as IMT-2000 (International Mobile  
Telecommunications 2000) and MMAC (Multimedia Mobile Access  
Communication). However, in the IMT-2000, it is possible to  
35 realize the communication speed of 2 Mbit/sec. while at

rest, but the maximum speed that can be provided during a fast moving by an automobile is only 144 Kbit/sec. Also, the MMAC system can provide the transmission speed of 10 Mbit/sec. per user, but it can only handle a moving speed at a level of the walking speed so that it is impossible to receive services during a fast moving by an automobile.

Sub 10  
a1  
In addition to such a shortage of the transmission bandwidth at the radio access section, the handover for switching an access target radio base station for a moving subscriber can also be a source of degradation for the performance of the Internet access utilizing the mobile communication system. Namely, when the handover occurs, it is necessary to carry out a procedure for detecting a new access target radio base station, a procedure for establishing connection with this new access target radio base station, a procedure for terminating connection with the previous access target radio base station, as well as a management of the subscriber's move for the purpose of continuing the data transmission to the subscriber.

20 In the case where the subscriber wishes to receive the downloading service through the Internet, a data server that is the downloading source cannot recognize the radio base station to which the downloading data destined to that subscriber should be sent, until the connection with the new access target radio base station is established. 25 Namely, only after the handover is finished, the data server can recognize the new access target radio base station and restart the transmission of the downloading data to the subscriber through that radio base station if 30 the transmission has not been completed yet. At this point, the time available for the data transmission using the radio base station will become shorter as much as the time required for the handover control becomes longer, and this can cause the lowering of the data transmission speed.

35 As described above, considering the fact that the

standard communication speed in the current mobile communication system and the next generation radio access system currently under the discussions is 10 Mbit/sec. in the wired LAN, the communication speed under the fast  
5 moving environment is hardly sufficient for comfortably receiving services through the Internet. Also, the handover control to be executed in conjunction with the occurrence of the handover can be a cause for the lowering of the data transmission speed.

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#### BRIEF SUMMARY OF THE INVENTION

It is therefore an object of the present invention to  
15 provide radio communication system and method in which a fast downloading service can be received comfortably without a failure, even in the case of providing packet communications such as those for the Internet access using a moving body capable of executing a fast moving such as  
20 automobile.

According to one aspect of the present invention there is provided a radio communication system, comprising: a plurality of radio base stations having respective service areas; a mobile radio terminal configured to transmit a  
25 data transmission request through one radio base station and receive requested data through at least one radio base stations; a radio control station connected with the radio base stations and having: a moving route prediction unit configured to predict a moving route of the mobile radio  
30 terminal according to a terminal location information obtained from the mobile radio terminal upon receiving the data transmission request; and a server unit configured to select those radio base stations which have service areas containing at least a part of the moving route predicted by  
35 the moving route prediction unit, and deliver the requested

data to selected radio base stations.

According to another aspect of the present invention there is provided a radio control station in a radio communication system formed by a plurality of radio base stations having respective service areas and a mobile radio terminal configured to transmit a data transmission request through one radio base station and receive requested data through at least one radio base stations, the radio control station comprising; a moving route prediction unit  
10 configured to predict a moving route of the mobile radio terminal according to a terminal location information obtained from the mobile radio terminal upon receiving the data transmission request from the mobile radio terminal through the one radio base station; and a server unit  
15 configured to select those radio base stations which have service areas containing at least a part of the moving route predicted by the moving route prediction unit, and deliver requested data to selected radio base stations.

According to another aspect of the present invention  
20 there is provided a radio communication method in a radio communication system formed by a plurality of radio base stations having respective service areas and a mobile radio terminal configured to transmit a data transmission request through one radio base station and receive requested data  
25 through at least one radio base stations, the radio communication method comprising; predicting a moving route of the mobile radio terminal according to a terminal location information obtained from the mobile radio terminal upon receiving the data transmission request from  
30 the mobile radio terminal through the one radio base station at a radio control station; selecting those radio base stations which have service areas containing at least a part of the moving route predicted by the predicting step at the radio control station; and delivering requested data  
35 from the radio control station to those radio base stations

selected by the selecting step.

According to another aspect of the present invention there is provided a computer usable medium having computer readable program codes embodied therein for causing a  
5 computer to function as a radio control station in a radio communication system formed by a plurality of radio base stations having respective service areas and a mobile radio terminal configured to transmit a data transmission request through one radio base station and receive requested data  
10 through at least one radio base stations, the computer readable program codes include: a first computer readable program code for causing said computer to predict a moving route of the mobile radio terminal according to a terminal location information obtained from the mobile radio  
15 terminal upon receiving the data transmission request from the mobile radio terminal through the one radio base station; and a second computer readable program code for causing said computer to select those radio base stations which have service areas containing at least a part of the  
20 moving route predicted by the moving route prediction unit, and deliver requested data to selected radio base stations.

Other features and advantages of the present invention will become apparent from the following description taken  
25 in conjunction with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

30 Fig. 1 is a block diagram showing a configuration of a radio communication system according to the first embodiment of the present invention.

Fig. 2 is a diagram showing an outline of a radio communication method to be carried out in the radio  
35 communication system of Fig. 1.

Fig. 3 is a flow chart for a processing procedure of the radio communication method to be carried out in the radio communication system of Fig. 1.

Fig. 4 is a sequence chart for an operation sequence  
5 in the radio communication system of Fig. 1 according to the radio communication method of Fig. 3.

Fig. 5 is a diagram showing an exemplary case of a moving route prediction by a moving route prediction device in the radio communication system of Fig. 1.

10 Fig. 6 is a sequence chart for an operation sequence of a radio communication method according to the second embodiment of the present invention.

Fig. 7 is a block diagram showing a configuration of a radio communication system according to the third  
15 embodiment of the present invention.

Fig. 8 is a diagram showing an exemplary case of a service area staying time calculation in the radio communication system of Fig. 7.

Fig. 9 is a sequence chart for an operation sequence  
20 in the radio communication system of Fig. 7 according to a first data transmission procedure.

Fig. 10 is a sequence chart for an operation sequence in the radio communication system of Fig. 7 according to a second data transmission procedure.

25 Fig. 11 is a diagram showing an outline of a radio communication method to be carried out in the radio communication system of Fig. 7.

Fig. 12 is a diagram showing an outline of a radio communication method according to the fourth embodiment of  
30 the present invention in one exemplary case.

Fig. 13 is a diagram showing an outline of a radio communication method according to the fourth embodiment of the present invention in another exemplary case.

Fig. 14 is a diagram showing an outline of a radio  
35 communication method according to the fourth embodiment of

the present invention in still another exemplary case.

Fig. 15 is a diagram showing an outline of a radio communication method according to the fifth embodiment of the present invention in one exemplary case.

5 Fig. 16 is a block diagram showing a configuration of a radio communication system according to the sixth embodiment of the present invention.

Fig. 17 is a block diagram showing a detailed configuration of a radio base station in the radio  
10 communication system of Fig. 16.

Fig. 18 is a block diagram showing a configuration of a receiving multi-beam formation circuit in the radio base station of Fig. 17.

Fig. 19 is a block diagram showing a configuration of  
15 a receiving beam formation circuit in the receiving multi-beam formation circuit of Fig. 18.

Fig. 20 is a block diagram showing a configuration of a transmitting multi-beam formation circuit in the radio base station of Fig. 17.

20 Fig. 21 is a block diagram showing a configuration of a transmitting beam formation circuit in the transmitting multi-beam formation circuit of Fig. 20.

Fig. 22 is a diagram showing one exemplary beam pattern to be formed by the radio base station of Fig. 17  
25 in a vicinity of a crossing.

Fig. 23 is a diagram showing another exemplary beam pattern to be formed by the radio base station of Fig. 17 in a vicinity of a crossing.

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#### DETAILED DESCRIPTION OF THE INVENTION

Referring now to Fig. 1 to Fig. 23, the embodiments of radio communication system and method according to the  
35 present invention will be described in detail. In the

following, the same or similar portions will be given the same or similar reference numerals in the drawings.

(First Embodiment)

5 Fig. 1 shows a configuration of a radio communication system according to the first embodiment of the present invention. As shown in Fig. 1, this radio communication system comprises: a radio control station 10; a communication network 12 such as the Internet to which the  
10 radio control station 10 is connected; a plurality of radio base stations  $14n-1$ ,  $14n$  and  $14n+1$  for carrying out wired communications with the radio control station 10 through the communication network 12; and a radio terminal 18 for carrying out radio communications with the radio base  
15 stations  $14n-1$ ,  $14n$  and  $14n+1$  while being located in service areas  $16n+1$ ,  $16n$  and  $16n+1$  of the radio base stations  $14n-1$ ,  $14n$  and  $14n+1$ .

Here, the radio control station 10 is a data delivery center for delivering various types of data (music, video,  
20 advertisement information) to the radio terminal 18 of the subscriber. This radio control station 10 at least has a moving route prediction device 1001 for predicting a moving route of the radio terminal 18 and a server 1002 for temporarily storing data requested from the radio terminal  
25 18 and transmitting that data to the radio terminal 18. In Fig. 1, both the moving route prediction device 1001 and the server 1002 are provided inside the radio control station 10, but the present invention is not necessarily limited to this specific case. For example, the the moving  
30 route prediction device 1001 and the server 1002 can be provided outside the radio control station 10 and connected to the radio control station 10 through the communication network 12.

The radio terminal 18 can be a portable terminal  
35 (mobile phone, cellular phone) on an automobile, a train,



or other vehicle running on road, railroad, etc. In Fig. 1, the radio terminal is located in the service area 16n-1 covered by the radio base station 14n-1. Consequently, the radio terminal 18 transmits the communication data by  
5 transmitting/receiving radio signals with respect to the radio base station 14n-1.

Next, with references to Fig. 2 to Fig. 4, the radio communication method according to the first embodiment of the present invention will be described. Fig. 2 shows an  
10 outline of this radio communication method, Fig. 3 shows a processing procedure of this radio communication method, and Fig. 4 shows an operation sequence among the radio control station 10, the radio base stations 14 and the radio terminal 18. In Fig. 2 to Fig. 4, it is assumed that  
15 the radio terminal 18 sequentially moves from a location of the radio terminal 18a to locations of the radio terminals 18b, 18c and 18d as the time elapses.

(1) When the radio terminal 18 enters the service area 16n-1 of the radio base station 14n-1, the radio terminal  
20 18 notifies a message indicating that it is located within the service area 16n-1 to the radio base station 14n-1 (step S101 of Fig. 3). In the following, the processing for notifying this message will be referred to as "within-area notice". Also, the radio terminal 18 carries out a  
25 connection set up for the purpose of carrying out communications with the radio base station 14n-1 according to the need.

(2) Next, the radio terminal 18 transmits a message indicating a data transmission request to the radio control  
30 station 10 (step S102 of Fig. 3). This data transmission request contains an identifier for indicating the radio base station with which the radio terminal 18 is currently capable of communicating. The radio control station 10 can recognize the radio base station with which the radio  
35 terminal 18 is currently capable of communicating, from the

identifier contained in this data transmission request. Here, the radio control station 10 recognizes that the radio terminal 18 is currently capable of communicating with the radio base station 14n-1.

5       (3) Upon receiving the data transmission request from the radio terminal 18, the radio control station 10 takes out requested data from a prescribed database (not shown), and temporarily stores the requested data in the server 1002 (step S103 of Fig. 3).

10       (4) When the storing of the data into the server 1002 is finished, the radio control station 10 predicts a moving route of the radio terminal 18 using the moving route prediction device 1001 (step S104 of Fig. 3). The moving route prediction device 1001 predicts the moving route of  
15 the radio terminal 18 according to the data transmission request transmitted from the radio terminal 18.

The moving route prediction can be realized as follows, for example. Fig. 5 shows an exemplary situation in which the moving route is to be predicted by the moving  
20 route prediction device 1001. In Fig. 5, five radio base stations 14n-2, 14n-1, 14n, 14n+1 and 14n+2 including the radio base stations 14n-1, 14n and 14n+1 shown in Fig. 1 are arranged, and it is assumed that the radio terminal 18 moves from the service area 16n-1 of the radio base station  
25 14n-1 through the service area 16n of the radio base station 14n to the service area 16n+1 of the radio base station 14n+1 as the time elapses.

In this example of Fig. 5, the radio control station 10 recognizes that the radio terminal 18 is currently  
30 located in the service area 16n-1 of the radio base station 14n-1 by receiving the data transmission request transmitted from the radio terminal 18.

Then, the moving route prediction device 1001 of the radio control station 10 searches for movable areas of the  
35 radio terminal 18 starting from the service area 16n-1 of

the radio base station 14n-1. At the same time, the radio control station 10 estimates a time required in delivering the data requested by the radio terminal 18 to the radio terminal 18. Then, all the movable areas of the radio terminal 18 within the estimated delivery time are set as the moving route candidates. Here, at a time of estimating the time required for the data delivery with respect to the radio terminal 18, it is preferable to account for the level of congestion in the communication network 12. In Fig. 5, a shaded region A is the predicted moving routes of the radio terminal 18.

(5) The radio control station 10 determines the radio base stations to which the data are to be delivered (data delivery radio base stations) from the moving routes of the radio terminal 18 predicted by the moving route prediction device 1001 (step S105 of Fig. 3). For example, when the moving routes of the radio terminal 18 are predicted as indicated in Fig. 5, the radio base stations 14n-2, 14n, 14n+1 and 14n+2 responsible for the service areas 16n-2, 16n, 16n+1 and 16n+2 that cover these moving routes are judged as the radio base stations from which the downloading of the requested data with respect to the radio terminal 18 is possible. Then, the radio control station 10 delivers the requested data stored in the server 1002 earlier to the radio base stations 14n-2, 14n, 14n+1 and 14n+2 (step S106 of Fig. 3).

(6) When the radio terminal 18 moves into the service area 16n of the radio base station 14n, the radio terminal 18 transmits the within-area notice indicating that it is located within the service area 16n to the radio base station 14n (step S107 of Fig. 3). Upon receiving the within-area notice, the radio base station 14n carries out a connection set up for the purpose of carrying out communications with the radio terminal 18.

(7) The radio base station 14n recognizes that the

radio terminal 18 is located within the service area 16n by receiving the within-area notice from the radio terminal 18. Then, the radio base station 14n transmits the requested data delivered from the radio control station 10 earlier to the radio terminal 18 (step S108 of Fig. 3).

(8) In the case where it is impossible to download all the data while the moving radio terminal 18 is located within the service area 16n of the radio base station 14n (step S109 NO in Fig. 3), the radio terminal 18 transmits the within-area notice to the radio base station 14n+1 next (step S107 of Fig. 3). Upon receiving the within-area notice, the radio base station 14n+1 carries out a connection set up for the purpose of carrying out communications with the radio terminal 18.

(9) The radio base station 14n+1 recognizes that the radio terminal 18 is located within the service area 16n+1 by receiving the within-area notice from the radio terminal 18. Then, the radio base station 14n+1 transmits the requested data delivered from the radio control station 10 earlier to the radio terminal 18 again (step S108 of Fig. 3).

(10) In the case where it is possible to download all the data while the moving radio terminal 18 is located within the service area 16n+1 of the radio base station 14n+1 (step S109 YES in Fig. 3), the processing is terminated.

Note that, in Fig. 5, the data are also delivered from the radio control station 10 to the radio base stations 14n-2 and 14+2 as well. However, as a result of the fact that the radio terminal 18 did not pass through the service area 16n-2 of the radio base station 14n-2 and the service area 16n+2 of the radio base station 14n+2, the data transmission from the radio base stations 14n-2 and 14n+2 to the radio terminal 18 will not be carried out.

35

(Second Embodiment)

Next, the second embodiment of the present invention will be described in detail.

In the first embodiment described above, the location  
5 of the radio terminal 18 is comprehended by identifying the  
radio base station 14 that is connected to the radio  
terminal 18. Namely, the radio control station 10 detects  
the location of that radio base station 14 by acquiring the  
10 identifier of the radio base station 14 contained in the  
data transmission request transmitted from the radio  
terminal 18. Then, the location of the radio terminal 18 is  
identified as the service area 16 of that radio base  
station 14 according to the detected information. However,  
15 in the radio access system such as IMT-2000, the service  
area of the radio base station is expected to have a radius  
of about 1 Km (or more than several Km in some cases), so  
that the use of such a wide range area as the location  
information of the radio terminal can be problematic.

In this second embodiment, a GPS (Global Positioning  
20 System) function is additionally provided in the radio  
terminal 18 of the first embodiment, such that the location  
information (longitude, latitude) of the radio terminal 18  
can be obtained more accurately. As a result, according to  
the second embodiment, the requested data can be  
25 transmitted to the radio terminal more quickly and surely.

Fig. 6 shows an operation sequence among the radio  
control station 10, the radio base stations 14 and the  
radio terminal 18 according to the second embodiment. In  
the second embodiment, the radio terminal 18 is equipped  
30 with the GPS function such as that used in the car  
navigation system or the like. As shown in Fig. 6, the GPS  
equipped radio terminal 18 calculates the longitude and the  
latitude by receiving radio signals arriving from a GPS  
satellite. Then, the current location of the radio terminal  
35 18 indicated by the calculated longitude and latitude is

notified to the radio control station 10 periodically (current location notice), so that the radio control station 10 can identify the accurate location of the radio terminal 18.

5        According to the second embodiment, the radio terminal 18 notifies the location information according to the GPS to the radio control station 10 periodically, so that the radio control station 10 can comprehend the current location of the radio terminal 18 at higher precision. For  
10 this reason, the radio control station 10 can make a more reliable prediction for the moving route of the radio terminal 18,

(Third Embodiment)

15        Next, the third embodiment of the present invention will be described in detail.

In the first and second embodiment described above, the moving route of the radio terminal 18 is predicted according to the location information notified from the  
20 radio terminal 18. In this third embodiment, a more accurate moving route prediction for the radio terminal 18 is realized by utilizing in addition traffic information such as a moving speed of the radio terminal 18, the legal speed limit of the moving route, a current moving speed of  
25 vehicles existing on the moving route, a signal change pattern of traffic signals existing on the moving route, etc.

Fig. 7 shows an exemplary configuration of the radio communication system according to the third embodiment. In  
30 this third embodiment, the moving speed of the radio terminal 18 (subscriber A) is either detected by a sensor (electromagnetic sensor, optical sensor, etc.) provided on the radio terminal 18 or given by a speed value indicated by the speedometer of the vehicle when the radio terminal  
35 18 is on the vehicle, for example. Then, this moving speed

is notified to the radio control station 10 periodically along with the location information according to the GPS. The radio control station 10 searches for the traffic information regarding an area in which the radio terminal 18 is currently located, according to the notified information regarding the current location and the moving speed, and predicts the moving route of the radio terminal 18 according to the obtained information.

In the third embodiment shown in Fig. 7, the above described traffic information is managed in a road traffic information system 20 connected to the communication network 12. The radio control station 10 requests the current traffic information to the road traffic information system 20 according to the need, and in response to this request, the road traffic information system 20 provides the current traffic information to the radio control station 10. Note that, in Fig. 7, the road traffic information system 20 is provided at a location physically different from that of the radio control station 10, but it is also possible to provide the road traffic information system 20 inside the radio control station 10 as a constituent element of the radio control station 10.

Here, the moving route prediction by the radio control station 10 requires the estimation of an amount of data to be delivered to each radio base station 14 that is the connection target of the radio terminal 18. This amount of data indicates an amount of data that can be downloaded to the radio terminal 18 while the radio terminal 18 is located within the service area 16 of each radio base station 14. In the third embodiment, this amount of data is predicted according to an estimated time for the radio terminal 18 to stay in each service area 16, the data transmission speed with respect the radio terminal 18, and a procedure for transmitting data to the radio terminal 18 within the service area 16.

First, the method for calculating the estimated staying time of the radio terminal 18 will be described.

Fig. 8 shows an exemplary situation for calculating the service area staying time. In Fig. 8, the radius of the service area 16 of the radio base station 14 is assumed to be "a Km", while the moving speed of the radio terminal 18 passing through the service area 16 is assumed to be "b Km/h". Here, the moving speed of the radio terminal 18 is set to be the smaller one of the following two speeds:

- 10 (a) the legal speed limit within the service area obtained from the traffic information; and
- (b) the current moving speed of the other vehicle (radio terminal) existing in the service area.

This speed setting is used in order to account for the state involving the vehicle flow slower than the legal speed limit due to the occurrence of the traffic jam within the service area.

As shown in Fig. 8, when the speed by which the radio terminal 18 of the subscriber passes through the service area 16 is "b Km/h", the time for which the radio terminal 18 exists within the service area 16 is given by "a/b" hour. The radio control station 10 obtained the amount of data that can be completely downloaded to the radio terminal 18 within this time, according to the calculated staying time. Note that the moving speed of the radio terminal 18 may be given by the moving speed measured by the radio terminal 18 that is periodically notified from the radio terminal 18 along with the location information.

Next, the procedure for transmitting data to the radio terminal 18 will be described. When the radio terminal 18 enters the service area 16 of the radio base station 14, the radio terminal 18 notifies a message indicating that it is currently located within the service area 16 of the radio base station 14, to that radio base station 14 (within-area notice). The radio base station 14 starts the



downloading for transmitting the data delivered from the radio control station 10 in advance, to the radio terminal 18 upon receiving this notice.

Now, in general, in the case of carrying out  
5 communications using a radio channel, there is a problem that the propagation loss varies largely due to the influence of the fading caused by the multi-path propagation such that the reliability of the transmission is considerably degraded at sections where the receiving  
10 level drops significantly. This phenomenon becomes particularly prominent in the case where the radio terminal 18 is moving fast. For this reason, the possibility for the radio terminal 18 to be able to receive all the data correctly while staying within the service area 16 of the  
15 radio base station 14 can be unlimitedly low, and as a result, some data of the downloading data may be lost.

In order to prevent this loss of some data of the downloading data, the following data transmission procedure can be adopted, for example. Fig. 9 shows an operation  
20 sequence for the first procedure for transmitting data from the radio base station 14 to the radio terminal 18. As shown in Fig. 9, in this first data transmission procedure, the radio terminal 18 notifies information (ACK, acknowledgement) indicating that the downloading data were  
25 received correctly, or information (NAK, negative acknowledgement) indicating that the downloading data were not received correctly, to the radio base station 14. When NAK is received, the radio base station 14 re-transmits that downloading data that were not correctly received, to  
30 the radio terminal 18 (re-transmission control).

It is also possible to adopt the following data transmission procedure. Fig. 10 shows an operation sequence for the second procedure for transmitting data from the radio base station 14 to the radio terminal 18. As shown in  
35 Fig. 10, in this second data transmission procedure, the

radio base station 14 transmits each packet constituting the downloading data repeatedly for a plurality of times, to the radio terminal 18 (redundant transmission control). Fig. 10 shows an exemplary case of transmitting each packet  
5 four times repeatedly to the radio terminal 18.

It is also possible to adopt the third data transmission procedure in which the first and second data transmission procedures described above are executed simultaneously. Namely, in the third data transmission  
10 procedure, the radio base station 14 transmits each packet repeatedly for a plurality of times to the radio terminal 18. Then, the radio terminal notifies whether each packet that is transmitted for a plurality of times was received correctly at least once or not, to the radio base station  
15 14 using ACK or NAK.

Using the re-transmission control and the redundant transmission control described above, it becomes possible for the radio terminal 18 to receive the highly reliably downloading service from the radio base station 14.

20 Now, the amount of downloading data that can be transmitted to the radio terminal 18 in the service area 16 of the radio base station 14 must be determined by accounting for the time required for the re-transmission control or the redundant transmission control described  
25 above. For this reason, the radio control station 10 estimates an error rate of the data transmitted to the radio terminal 18 according to the propagation characteristics of the radio channel in the service area 16 of the target radio base station 14. Then, the time  
30 required for the re-transmission control to be executed in order to receive all the downloading data correctly is predicted in the case of executing the re-transmission control shown in Fig. 9. Also, the number of times for repeatedly transmitting each packet in order to receive all  
35 the downloading data correctly is predicted, and then the

time required for doing that is predicted, in the case of executing the redundant transmission control shown in Fig. 10.

The time for which the downloading at the radio base station 14 is possible is then set as a time obtained by subtracting the time required for the re-transmission control and/or the time required for the redundant transmission control from the staying time within the service area 16 of the radio base station 14. Then, the amount of downloading data that can be transmitted within that time is estimated as the amount of data that can be downloaded at that radio base station 14.

Next, with reference to Fig. 11, the radio communication method according to the third embodiment will be described. Fig. 11 shows an outline of the radio communication method according to the third embodiment. In Fig. 11, it is assumed that the radio terminal 18 receives the service as defined by the IMT-2000.

In Fig. 11, the radio terminal 18 is requesting the downloading of data in amount of 5 Mbytes to the radio control station 10. Also, each one of the radio base stations 14n-1, 14n and 14n+1 as well as the other radio base stations not shown in the figure is providing services at the data communication speed of 144 Kbit/sec. for the fast moving case as defined by the IMT-2000. Each of the service areas 16n-1, 16n and 16n+1 is a circular region with a 4 Km diameter centered around the radio base station 14. When the legal speed limit and the current moving speed within the service area 16 are both 60 Km/h, the staying time of the radio terminal 18 within this service area 16 can be predicted as  $4/60$  hour, i.e., 240 sec.

Then, when the radio control station 10 judges to allocate  $1/2$  of that staying time to the re-transmission control described above, for example, the downloading possible time is given by 120 sec. Consequently, the amount

of data that can be downloaded at one radio base station 14 is  $144 \text{ Kbit/sec.} \times 120 \text{ sec.} = 17280 \text{ Kbits}$ , i.e., 2.16 Mbytes. The radio terminal 18 is requesting the downloading of the data in amount of 5 Mbytes, so that the radio

5 control station 10 determines the delivery of this downloading data to three consecutive radio base stations.

Note that the data transmission speed of the communications between the radio base station 14 and the radio terminal 18 varies according to the radio channel  
10 utilization state at the radio base station 14. For this reason, the data transmission speed to be used at a time of estimating the amount of data that can be downloaded should preferably be set by accounting for the radio channel  
15 utilization rate at that point. Also, a ratio of the staying time that is to be allocated to the re-transmission control may be adjusted whenever necessary at the radio control station 10 according to the data error states of the downloading operations carried out in the past.

#### 20 (Fourth Embodiment)

Next, the fourth embodiment of the present invention will be described in detail.

This fourth embodiment is directed to a method for selecting the radio base station to deliver the downloading  
25 data to the radio terminal 18 in the case where a crossing with a traffic signal exists on the predicted moving route of the radio terminal 18.

Fig. 12 shows an exemplary case where the radio terminal 18 that made the data transmission request at time  
30  $t_0$  passes through a crossing with a traffic signal at time  $t_0 + T$ .

In Fig. 12, the radio control station 10 can easily predict a time at which the radio terminal 18 passes the crossing with the traffic signal, from a distance from the  
35 combination.

current location of the radio terminal 18 to that crossing,  
and the moving speed of the radio terminal 18 (which is the  
smaller one of the legal speed limit on a route between  
these two points and the current moving speed of vehicles  
5 existing on that route). Also, the which signal light of  
the traffic signal will be on when the radio terminal 18  
reaches to the crossing can be predicted by receiving  
information regarding the signal change pattern of the  
traffic signal from the road traffic information system 20  
10 because the traffic signal changes the signal light  
periodically according to a prescribed signal change  
pattern.

For example, in Fig. 12, when the radio control  
station 10 predicts that the signal light of the traffic  
15 signal at a time of the arrival of the radio terminal 18 to  
the crossing will be green, it can be expected that the  
radio terminal 18 will not stop at that crossing and will  
continue to move fast as before. In this case, the radio  
base station 14 to deliver the downloading data is selected  
20 by predicting the moving route of the radio terminal 18  
without taking the traffic signal into consideration,  
similarly as in the case of the third embodiment described  
above.

On the other hand, when the radio control station 10  
25 predicts that the signal light of the traffic signal at a  
time of the arrival of the radio terminal 18 to the  
crossing will be red, it can be expected that the radio  
terminal 18 will stop at that crossing. While the radio  
terminal 18 is stopping, the data communication speed for  
30 radio signals from the radio base station 14 to the radio  
terminal 18 can be made faster than the data communication  
speed in the case where the radio terminal 18 is moving  
fast.

For example, in the case of utilizing the IMT-2000,  
35 the data communication speed at a time of the fast moving

is 144 Kbit/sec. whereas the data communication speed at rest can be as high as 2 Mbit/sec. Moreover, while stopping, it is even possible to receive the service at the data communication speed of 10 Mbit/sec. that is provided  
5 by the MMAC system.

Fig. 13 shows an exemplary case of estimating the amount of data that can be downloaded at each radio base station and predicting the moving route according to the estimated amount of data, when the signal light of the  
10 traffic signal at the crossing on the moving route is predicted as red. In Fig. 13, it is assumed that the radio terminal 18 receives the service as defined by the IMT-2000.

In Fig. 13, the radio terminal 18 is requesting the  
15 downloading of data in amount of 5 Mbytes to the radio control station 10. Over the distance of 6 Km since the data transmission request is made until the radio terminal 18 reaches to the crossing where it is expected to stop, the radio terminal 18 receives the service at the data  
20 communication speed of 144 Kbit/sec. for the fast moving case as defined by the IMT-2000. Assuming that the radio terminal 18 is moving at the speed of 60 Km/h, the amount of data that can be downloaded at the service area 16n-1 of the radio base station 14n-1 is 2.16 Mbytes. In addition,  
25 the service is provided to the radio terminal 18 also at 144 Kbit/sec. even over the distance of 2 Km until the radio terminal 18 reaches to the crossing, and the amount of data that can be downloaded while moving fast within the service area 16n of the radio base station 14n is 1.08  
30 Mbytes.

Then, during 30 seconds for which the radio terminal 18 stops at the crossing, the service is provided to the radio terminal 18 at the data communication speed of 2 Mbit/sec. for the stopping case as defined by the IMT-2000.  
35 The remaining amount of the downloading data is  $5 - 2.16 -$

1.08 = 1.76 Mbytes, so that using the data delivery at 2 Mbit/sec., the downloading can be completed in  $1.76 \times 8(\text{Mbits})/2(\text{Mbit/sec.}) = 7.04$  seconds of the time.

Consequently, the radio control station 10 determines the delivery of 2.16 Mbytes of the downloading data to the radio base station 14n-1 and the delivery of 2.84 Mbytes of the downloading data to the radio base station 14n.

Note that, in Fig. 13, at a time of estimating the amount of downloading data while stopping, the time to be allocated to the re-transmission control is not taken into consideration because the reliability of the data transmission through the radio channel improves considerably while stopping compared with the case of the fast moving. Of course, it is also possible to estimate the amount of downloading data by taking the time to be allocated to the re-transmission control into consideration.

In the example of Fig. 13, the downloading of the data is carried out both while the radio terminal 18 is moving and while the radio terminal 18 is stopping, but it is also possible to carry out the downloading of the data only while the radio terminal 18 is stopping, without providing any data while the radio terminal 18 is moving. In this case, the data communication at the faster speed can be provided compared with the data communication under the environment where the radio terminal 18 is moving fast, and the possibility for causing the loss of the downloading data due to the propagation loss on the radio channel becomes low so that it becomes possible to provide the more reliable downloading service in shorter time.

Fig. 14 shows another exemplary case of estimating the amount of data that can be downloaded at each radio base station and predicting the moving route according to the estimated amount of data, when the signal light of the traffic signal at the crossing on the moving route is

predicted as red, which is different from that of Fig. 13. In Fig. 14, it is also assumed that the radio terminal 18 receives the service as defined by the IMT-2000.

In Fig. 14, it is predicted that the radio terminal 18 will be stopping for 30 seconds because the signal light of the traffic signal is red at the crossing within the service area 16n of the radio base station 14n. In this case, the radio control station 10 judges whether the downloading of the data (5 Mbytes) requested from the radio terminal 18 can be completed during that 30 seconds or not. In this example, the the service is provided to the radio terminal 18 at the data communication speed of 2 Mbit/sec. for the stopping case as defined by the IMT-2000, so that the time required for the downloading of 5 Mbytes data is  $5 \times 8(\text{Mbits}) / 2(\text{Mbit/sec.}) = 20$  seconds. Consequently, the radio control station 10 judges that the downloading of 5 Mbytes data can be completed while the radio terminal 18 is stopping at the crossing, and determines the delivery of 5 Mbytes downloading data to the radio base station 14n.

On the other hand, when it is judged that the downloading of the requested data cannot be completed while the radio terminal 18 is stopping at the crossing, the radio control station 10 determines to carry out the downloading of a part of the requested data while the radio terminal 18 is under the fast moving environment before reaching to the crossing.

Also, when it is judged that the downloading of the requested data can be completed while the radio terminal 18 is under the fast moving environment before the radio terminal 18 stops at the crossing, the radio control station 10 determines to carry out the downloading only under the fast moving environment without carrying out the downloading at the crossing, in order to shorten the downloading time.



(Fifth Embodiment)

Next, the fifth embodiment of the present invention will be described in detail.

In the third and fourth embodiments described above,  
5 the amount of downloading data to be transmitted to the radio terminal 18 at each radio base station 14 is estimated in advance by accounting for the time required for the re-transmission control or the redundant transmission control. However, if the radio channel quality  
10 becomes considerably poorer than the expected quality when the radio terminal 18 actually receives the downloading service, there is a possibility for the amount of data correctly downloaded from the radio base station 14 becomes less than the originally estimated amount. In such a case,  
15 there is a need to supplement the non-received data by having them re-transmitted from a radio base station with which the radio terminal 18 will become capable of communicating subsequently.

In order to realize such a supplement of the  
20 downloading data, in this fifth embodiment, the radio terminal 18 notifies the downloading data reception state up to that point to a next radio base station 14 when the radio terminal 18 moves to the service area 16 of the next radio base station 14. Upon receiving this reception state  
25 notice, the next radio base station 14 checks whether the non-received downloading data exists in the downloading data that are supposed to be received by the radio terminal 18 or not. If the non-received downloading data exists, the next radio base station 14 transmits the non-received  
30 downloading data in addition to the originally allocated downloading data, to the radio terminal 18.

Fig. 15 shows an operation sequence among the radio control station 10, the radio base station 14 and the radio terminal 18 in the case of supplementing the non-received  
35 downloading data at the next radio base station 14. In Fig.

15, it is assumed that the downloading data to be transmitted to the radio terminal 18 are given by eight packets (packets #1 to #8).

In the example of Fig. 15, when the radio terminal 18 enters the service area  $16n+1$  of the next radio base station  $14n+1$ , the radio terminal 18 notifies the downloading data reception state up to that point to the radio base station  $14n+1$  along with a message indicating that it is located within the service area  $16n+1$ . More specifically, the radio terminal 18 notifies that the packets #1, #3 and #4 have already been received to the radio base station  $14n+1$ . According to this reception state notice, the radio base station  $14n+1$  recognizes that the packet #2 is the non-received downloading data of the radio terminal 18. Consequently, the radio base station transmits the packet #2 in addition to the originally allocated packets #5 to #8 to the radio terminal 18.

Note that when the radio base station  $14n+1$  does not have the packet #2 to be re-transmitted, the radio base station  $14n+1$  notifies to the radio control station 10 that there is a need to re-transmit the packet #2 to the radio terminal 18. Upon receiving this notice, the radio control station 10 delivers the packet #2 to the radio base station  $14n+1$  or a radio base station with which the radio terminal 18 will become capable of communicating subsequently.

In this way, by notifying the downloading data reception state of the radio terminal 18 to the next radio base station, it becomes possible to supplement the unexpectedly lost downloading data easily at the next radio base station. As a result, it is possible to expect the further improvement of the reliability of the downloading service.

#### (Sixth Embodiment)

Next, the sixth embodiment of the present invention

will be described in detail.

Fig. 16 shows a configuration of a radio communication system according to the sixth embodiment of the present invention. As shown in Fig. 16, this radio communication system comprises: a traffic control device 50; a communication network 52 such as the Internet to which the traffic control station 50 is connected; a radio base station 54 and a traffic signal 56 which are connected through the communication network 52; and a radio terminal 58 for carrying out radio communications with the radio base station 14.

The radio base station 54 has at least an antenna device 62 which is formed by a plurality of antenna elements 60 and capable of forming a plurality of beam patterns, a modulation unit (not shown) for modulating transmission data, and a demodulation unit (not shown) for demodulating received radio signals. Of course, it is also possible to use a configuration using a modulation/demodulation unit in which the modulation unit and the demodulation unit are integrated.

Then, a plurality of beam areas (not shown) formed by the beam patterns of the radio base station 54 constitute the service area of this radio base station 54. The radio base station 54 executes transmission/reception of radio signals with respect to the radio terminal 58 having a radio signal transmission/reception function which is located within the service area, by forming a plurality of beam patterns.

The radio terminal 58 can be a vehicle running on road or the like or a portable terminal (mobile phone, cellular phone) or the like on that vehicle.

Fig. 17 shows a detailed configuration of the radio base station 54. In Fig. 17, the number of antenna elements 60 in the antenna device 62 is assumed to be four and the antenna device 62 is assumed to be shared by a transmitting

side and a receiving side, for the sake of the simplicity.

As shown in Fig. 17, switches 5405 are connected to the antenna elements 60 in correspondences to respective antenna elements. Then, the switching between transmission  
5 and reception of the antenna device 60 is realized by switching the switches 5405.

In the receiving side, the signals received by the antenna elements 60 are entered into amplifiers (low noise amplifiers) 5406 corresponding to the respective antenna  
10 elements 60 through the switches 1006. The entered received signals are amplified by the amplifiers 5406.

The amplified received signals are applied with a frequency conversion from an RF band into an IF band or a baseband by frequency converters 5407. In this IF band or  
15 the baseband, the receiving multi-beam formation circuit 5408 forms a plurality of receiving beams simultaneously by carrying out a prescribed weighting with respect to each received signal outputted by each frequency converter 5407. This weighting is executed according to a weighting control  
20 device 5410.

Fig. 18 shows a detailed configuration of the receiving multi-beam formation circuit 5408 of Fig. 17. In Fig. 18, the number of beams to be simultaneously formed is assumed to be three. The received signals outputted from  
25 each frequency converter 5407 are entered into a corresponding receiving beam formation circuit 5411. Each receiving beam formation circuit 5411 combines the entered received signals by weighting them according to weights set by the weight control device 5410. Then, each receiving  
30 beam formation circuit 5411 outputs weighted and combined signals to a corresponding demodulation unit 5409.

Fig. 19 shows a detailed configuration of a receiving beam formation circuit 5411 of Fig. 18. The received signals outputted from each frequency converter 5407 are  
35 entered into a corresponding weighting circuit 5412, where

the prescribed weighting is carried out. Here, the method of weighting at the weighting circuit 5412 can be an amplitude weighting, a phase weighting, or an amplitude and phase weighting, for example. The weighted received signals  
5 are then combined by a combiner 5413.

On the other hand, in the transmitting side, the transmission signals modulated by the modulation units 5401 are outputted to the transmitting multi-beam formation circuit 5402 as shown in Fig. 17. The transmitting multi-  
10 beam formation circuit 5402 forms a plurality of receiving beams simultaneously by carrying out a prescribed weighting with respect to each transmission signal modulated by each modulation unit 5401. This weighting is also executed according to the weighting control device 5410. The amount  
15 of weight is set up such that the beam patterns of the transmitting side and the receiving side coincide with each other.

Fig. 20 shows a detailed configuration of the transmitting multi-beam formation circuit 5402 of Fig. 19.  
20 The transmission signals outputted from each modulation unit 5401 are entered into a corresponding transmitting beam formation circuit 5414. Each transmitting beam formation circuit 5414 combines the entered transmission signals by weighting them according to weights set by the  
25 weight control device 5410. Then, each transmitting beam formation circuit 5414 outputs weighted and combined signals to a corresponding frequency converter 5403.

Fig. 21 shows a detailed configuration of the transmitting beam formation circuit 5414 of Fig. 20. The  
30 transmission signals outputted from each modulation unit 5401 are split by a splitter 5416, and each split signal is entered into a corresponding weighting circuit 5415, where the prescribed weighting is carried out.

Then, as shown in Fig. 21, each one of four beams  
35 formed by the transmitting multi-beam formation circuit

5402 is applied with a frequency conversion into the RF band by a corresponding frequency converter 5403, and each frequency converted transmission signal is amplified by a corresponding amplifier (high output amplifier) 5404. Then, 5 the transmission signals are transmitted from the corresponding antenna elements 60 through the switches 5405.

In the radio communication system of this sixth embodiment, the radio base station 54 is connected with the 10 traffic control device 50 through the communication network 52, and receiving the control information regarding the signal light of the traffic signal 56 from the traffic control device 50. The radio base station 54 derives an appropriate amount of weight for a location of the radio 15 base station 54 by utilizing that control information at the weight control device 5410. Then, the beam pattern formed by the antenna device 60 is optimized by using the derived amount of weight.

Here, the optimization of the beam pattern is made 20 such that the directivity of the beams is pointed toward a direction of the traffic signal 56 with a "red" signal light on, and the directivity of the beams is set to be null for a direction of the traffic signal 56 with a "green" signal light on.

25 For example, in the case where the radio base station 54 is provided in a vicinity of a crossing 64 shown in Fig. 22, the radio base station 54 points the directivity of the beam pattern toward directions of traffic signals 66a and 66c with the red signal light on, so as to form service 30 areas 70a and 70b. In this way, the radio base station 54 becomes capable of communicating with a vehicle 68a that is stopping because of the red signal light.

Also, in the case where the radio base station 54 is provided in a vicinity of a crossing 72 shown in Fig. 23, 35 the radio base station 54 points the directivity of the

beam pattern toward a direction of a traffic signal 74b with the red signal light on, so as to form a service area 78. In this way, the radio base station 54 becomes capable of communicating with a vehicle 76b that is stopping  
5 because of the red signal light. Note that the radio base station 54 may be provided on the traffic signal 74b or at a place other than the location of the traffic signal 74b.

Here, the method for forming the beam pattern is not limited to any specific method. The traffic control  
10 information and the amounts of weights for beams are set in correspondence by some method and this correspondence information is stored in the weight control device 5410. Then, the weight control device 5410 sets the appropriate amounts of weights to the transmitting multi-beam formation  
15 circuit 5402 and the receiving multi-beam formation circuit 5408 according to the traffic control information provided from the traffic control device 50 through the communication network 52.

In this way, according to the sixth embodiment, the  
20 directivity of the beams is pointed toward a direction of a traffic signal with a red signal light on, so that it becomes possible to improve the antenna gain with respect to the radio terminal that is stopping or about to stop (slowly moving). For this reason, it is possible to improve  
25 the quality of radio communications with the communication target radio terminal.

As described above, according to the present invention, the moving route of the mobile terminal is  
30 predicted and the base station capable of transmitting data to the mobile terminal on the predicted moving route is selected. Then, the data requested from the mobile terminal are delivered to the selected base station in advance. For this reason, it becomes possible to shorten the time  
35 required for establishing a connection between the mobile

terminal and a new access target base station at a time of the handover, and consequently it becomes possible to transmit the data to the mobile terminal fast, without a failure.

5        Thus, according to the present invention, it becomes possible to provide radio communication system and method in which a fast downloading service can be provided without a failure, with respect to a moving body capable of executing a fast moving such as automobile.

10        It is to be noted that the above described embodiments according to the present invention may be conveniently implemented using a conventional general purpose digital computer programmed according to the teachings of the present specification, as will be apparent to those skilled  
15 in the computer art. Appropriate software coding can readily be prepared by skilled programmers based on the teachings of the present disclosure, as will be apparent to those skilled in the software art.

      In particular, the radio control station of each of  
20 the above described embodiments can be conveniently implemented in a form of a software package.

      Such a software package can be a computer program product which employs a storage medium including stored computer code which is used to program a computer to  
25 perform the disclosed function and process of the present invention. The storage medium may include, but is not limited to, any type of conventional floppy disks, optical disks, CD-ROMs, magneto-optical disks, ROMs, RAMs, EPROMs, EEPROMs, magnetic or optical cards, or any other suitable  
30 media for storing electronic instructions.

      It is also to be noted that, besides those already mentioned above, many modifications and variations of the above embodiments may be made without departing from the novel and advantageous features of the present invention.  
35 Accordingly, all such modifications and variations are



intended to be included within the scope of the appended claims.

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